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Impact of a brief auditory attention training on a modified colour-word Stroop task in a high anxiety and worry sample

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Abstract

Poor attentional control leads to attentional biases that are implicated in psychological distress. Attention Training Technique (ATT) is an auditory intervention designed to strengthen attentional control. Research indicates that ATT alleviates anxiety and depressive symptoms. This study is a randomized control trial with repeated measures that tested if a lab-based, single-exposure of ATT strengthened attentional control. Forty-six nonclinical, high anxiety/worry participants received either ATT or a sham control intervention. Attentional control was assessed using the standard and a modified version of the colour-word Stroop task. The modified version incorporated tactile interference to increase perceptual load. A series of mixed effects models, simple contrasts, and z-tests were used to evaluate if cross-modal interference worsened, and whether ATT was beneficial to, attentional control. Tactile interference increased reaction times but, when Stroop interference was controlled for, this was only true on incongruent trials. The impact of ATT was greatest under high perceptual load.

Keywords: attentional biases; attentional control; Attention Training Technique; Self-Regulatory Executive Function; Stroop task.

Attention, Attention Control and Attentional Biases

Attention requires a range of functions to allow effective and efficient present-moment cognitive processing (necessitated by the brain's limited capacity) that are both goal-driven (top-down) and stimulus-driven (bottom-up). Chun, Golomb, and Turk-Browne (2011) proposed a taxonomy of external and internal attention consisting of three basic functions: 'selection attention', 'modulation' and 'vigilance'. Selective attention allows relevant information to be processed, while inhibiting the processing of irrelevant stimuli. Modulation determines how this selected information is processed (including its management in working memory and its encoding into long-term memory) and characterizes responses to it. Finally, vigilance refers to how attentional modulation strategies are sustained over time.

'Attentional control' refers to the extent individuals can consciously marshal selective attention, modulation and vigilance (i.e., it is a top-down process). Attentional Control Theory purports that anxiety disrupts the balance between goal and stimulus drivers of attention by reducing top-down, and increasing bottom-up, control (resulting in impaired 'attentional control'), leading to 'attentional biases' that are argued to maintain anxiety (e.g., Eysenck, Derakshan, Santos, & Calvo, 2007; Fox, Russo, & Dutton, 2002). Attentional biases have been conceptualized as a tendency to focus attention towards, or away from, concern-relevant internal and external stimuli (Harvey, Watkins, Mansell, & Shafran, 2004). For example, individuals with poor attentional control may find it difficult to shift the orientation of their attention and disengage from concern-relevant stimuli (which can be described as an attentional bias). Attentional biases are associated with a broad range of psychiatric disorders and symptoms of psychological distress (e.g., Ingram, 1990; Mor & Winquist, 2002; Williams, Mathews, & MacLeod, 1996).

Measuring Attention and Attentional Control

Subjective (e.g., self-report questionnaires such as the Attentional Control Scale; Derryberry & Reed, 2001) and objective methods have been used to measure attention (and attentional control). The Stroop task (Stroop, 1935) is an objective measure of attention. In the colour-word version individuals are required to colour-name word stimuli as quickly as they can in each Stroop task trial, with reaction times (RTs: i.e., the latency between the presentation of stimuli and response) interpreted as a measure of attentional control. RTs are generated for each individual trial, which can be 'congruent' or 'incongruent'. In congruent trials, the meaning of word stimuli matches the presentation colour (e.g., the written word 'blue' presented in a blue colour), which contrasts with incongruent trials where word meaning and colour do not match (e.g., the written word 'blue' presented in a yellow or red colour), creating 'Stroop interference'. People are reliably slower to colour-name in incongruent trials compared to congruent trials, and this is referred to as the 'classical Stroop effect' (see MacLeod, 1991). The accuracy and speed of RTs are likely to involve a combination of attention stages, such as selection, modulation and vigilance (Lavie, Hirst, de Fockert, & Viding, 2004). Individuals with greater attentional control are quicker to colour-name in incongruent trials than those with poorer attentional control. Greater attentional control means a larger role for top-down processing, and a smaller role for bottom-up processing, in the functions of attention.

Modified versions of the Stroop task have been developed. For example, the emotional Stroop task variant uses concern-relevant stimuli - threatening words specific to an individual's psychopathology (see Williams et al., 1996 for a review). Individuals' RTs are increased when presented with threatening compared to neutral stimuli (referred to as the 'emotional Stroop effect'). However, there are issues with the emotional Stroop task. For example, the understanding and emotional valence of concern-related stimuli are likely to

vary between participants (e.g., Wingenfeld et al., 2006) and would need to be controlled for, increasing the number of parameters estimated in statistical modelling of study data.

Attention Training Technique

‘Attention Training Technique’ (ATT) is an auditory exercise designed to strengthen attentional control (Wells, 1990). Initial versions of ATT employed visual stimuli, but this was found ineffective compared to auditory (Wells, 2009). ATT was developed from the Self-Regulatory Executive Function (S-REF) model of psychopathology (Wells & Matthews, 1994, 1996). According to the S-REF model, both voluntary and involuntary mechanisms contribute to attentional biases; while some processing of stimuli is automatic and reflexive, attentional control is dynamic, primed by top-down processes. During ATT individuals are given instructions regarding how to orientate their attention. Following these instructions ‘trains’ the top-down control of attention. A recent systematic review tentatively concluded ATT is an effective intervention for reducing anxiety and depressive symptoms (Knowles, Foden, El-Deredy, & Wells, 2016). However, studies that have tested if ATT strengthens attentional control using objective measures of attention have reported mixed findings (e.g., Callinan, Johnson, & Wells, 2015; Sharpe et al., 2010).

Study Aims

The main objective of the present study was to test if a lab-based, single-exposure of ATT strengthens attentional control using an objective measure of attention and a randomized control design. The study incorporated several novel design characteristics to increase the robustness of its findings. Firstly, an auditory sham control intervention of a near equal duration to the auditory ATT experimental intervention was used. The control intervention is also used in ATT and consists of the same sounds as the experimental intervention. However, the experimental intervention included over-dubbed, spoken-word instructions that directed participants’ attention orientation - unlike the control intervention

for which no instructions regarding orientation were given (importantly, any previous exposure to ATT was an exclusion criterion for participant recruitment in the present study). Secondly, the present study employed the colour-word Stroop task and not the emotional Stroop task to eliminate between-participant variance due to individual differences in the emotional valence of concern-related stimuli. Thirdly, statistical analyses were used that did not aggregate Stroop task RTs (this statistical approach allowed a fine-grained analysis of the data to minimize information loss) and were able to model individual differences (Lo & Andrews, 2015). Fourthly, the present study used a modification of the colour-word Stroop task to increase task-irrelevant interference (thus amplifying the signal-to-noise ratio [SNR] and increase sensitivity to detect changes) by incorporating tactile interference conditions both for trials with Stroop interference (i.e., incongruent trials) and without (i.e., congruent trials). The Load Theory of Selective Attention asserts that the effectiveness and efficiency of selective attention is dependent on the processing demands of the current task (Lavie, 2005; Lavie et al., 2004), suggesting that RTs would be slower in trials where perceptual load (PL) is greatest (i.e., trials with both Stroop and tactile interference). Finally, to optimize the present study's ability to detect changes in attentional control, a nonclinical sample self-reporting high levels of anxiety/worry was recruited. This was because in a meta-analysis, conducted by Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, and Van Ijzendoorn (2007), reported that, while there was little evidence for attentional biases (that are associated with poor attentional control) in non-anxious adults, attentional biases are found in adults who self-reported high anxiety.

The present study tested three hypotheses. Firstly, the addition of tactile interference to the colour-word Stroop task would increase RTs (regardless of the presence of Stroop interference) and the combination of Stroop and tactile interference in a Stroop task trial would result in the greatest PL and the slowest RTs (hypothesis 1). The second and third

hypotheses stated that a lab-based, single-exposure of ATT, compared to a sham control intervention, (hypothesis 2) would improve attentional control (indicated by changes in RT data), and (hypothesis 3) that this would be more evident in trials with the most PL (i.e., trials with Stroop *and/or* tactile interference).

Method

Sample Size

No published studies evaluating ATT using colour-word Stroop task RTs were identified. However, a power analysis was conducted on data reported from a study by Luehring-Jones, Louis, Dennis-Tiwary, and Erbllich (2017) from an ANOVA analysis to estimate sample size. They used pre and post emotional Stroop task RTs to compare a single session of attentional bias modification to a sham control intervention and an effect size of 0.22. The power analysis recommended a sample size of 44 (at a power of 0.80) to find an effect size of 0.22.

Participants

Participants were recruited via circular emails sent to staff and students at King's College London and were screened using an online questionnaire. Eligibility criteria required participants: (1) had no previous experience of ATT, (2) scored above five on the General Anxiety Disorder 7 scale (GAD-7; Spitzer, Kroenke, Williams, & Löwe, 2006) and above 48 (75th percentile; Gillis, Haaga, & Ford, 1995) on the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) at screening, (3) had a good understanding of written and spoken English, (4) were aged 18 or above, and (5) had capacity to provide informed consent. Participants who completed the full study were paid £20. Ethical approval was received from the Psychiatry, Nursing, and Midwifery Research Ethics Subcommittee at King's College London (reference: HR15/161938).

Materials

Screening measures. These were online versions of the GAD-7 (seven items), which measures anxiety symptoms, and the 16-item PSWQ, measuring worry. Both have been used extensively in research and have well-established psychometric properties (e.g., Brown, Antony, & Barlow, 1992; Meyer et al., 1990; Spitzer et al., 2006).

Experimental and control interventions. For the current study, two audio tracks were downloaded from the Metacognitive Therapy Institute website ("Metacognitive Therapy Institute," 2019), which is an online resource for MCT clients and practitioners. Both consisted of approximately 12 minutes of simultaneous sounds. Over-dubbed, spoken-word instructions solely differentiated the experimental (ATT) from the sham control intervention. During the first part of the experimental intervention (lasting approximately 5 minutes), a voice instructed the listener to focus attention on a specific sound for around 10 to 15 seconds before disengaging and switching to another. The second part (lasting approximately 4 minutes) was like the first, except the instructions to switch focus occurred at a faster rate (every 3 to 4 seconds). In the final part (lasting approximately 3 minutes), the listener was asked to simultaneously attend to as many of the sounds as possible. Participants allocated to the control intervention were not given any instructions regarding how they should focus their attention while listening to the audio track. Currently, it is not possible to download ATT audio files because of earlier copywrite infringements. However, Wells (2009) presented a script for ATT, detailing the phases and suggesting auditory stimuli.

Stroop task and Stroop interference. The colour-word Stroop task was implemented using PsychoPy 2 (Peirce, 2014). Each participant completed four Stroop sessions. Each Stroop session comprised of a total of 60 trials (five blocks of 12 trials), with congruent and incongruent trials randomized and balanced within each block. This meant there were a total of nine colour-word 'stimuli pairs' (e.g., the written word 'red' presented in a red colour, the written word 'red' presented in a blue colour, etc.). Participants responded to

the presentation of stimuli by pressing a button (labelled 'blue', 'green', or 'red') on a Black Box ToolKit USB Response Pad (Plant, Hammond, & Turner, 2004).

Stroop task and tactile interference. A KOR-FX gaming vest (Immerz, 2014) was used to create tactile interference. This vest was designed to enhance 'immersiveness' by providing haptic feedback in response to video game sounds. An audio track was created to stimulate haptic feedback consisting of drum beats. The timing and frequency of the drum beats were ranged (approximately) from beats to 1 per second and were irregular (to reduce the likelihood of habituation). The drum beats were not heard by the participants during their two tactile interference Stroop sessions (the programmable drum beats were used to silently trigger haptic feedback). The present study's authors were unable to identify relevant research to guide the construction of the drumbeat audio track. The vest's status was either vibrating (V, creating tactile interference) or not vibrating (NV, the absence of tactile interference) for the entire duration of a single Stroop session. For example, for a participant over the study procedure, the vest would be vibrating during Stroop sessions one and three (or two and four), while not-vibrating for Stroop sessions two and four (or one and three).

Procedure

Figure 1 shows the participant flow through the study. Participants were randomly allocated to either the experimental or control condition by picking tokens out of a container. The same method was used to randomise the order of tactile interference across Stroop sessions. Participants were blinded to their allocated study condition. Participants read the study documentation before giving written consent and then completed a questionnaire booklet containing demographic items, the GAD-7 and the PSWQ.

Participants wore the vest throughout the study regardless of whether it was producing tactile interference (i.e., V or NV). Figure 2 illustrates the study procedure for participants in both experimental and control conditions and both orders of tactile

interference (V-NV[-V-NV] or NV-V[-NV-V]) across three stages (pre-intervention, intervention and post-intervention). In Stage 1, participants completed two Stroop sessions, one with tactile interference (V) and one without (NV). The order of tactile interference presentation was randomized between and within study condition.

In Stage 2, participants were administered either the experimental or control intervention. Participants allocated to the experimental condition were told the following before listening to the ATT audio track: *“I am now going to play you an audio file and ask you to listen to it while wearing these headphones. The audio file contains spoken-word instructions that I would like you to follow as best as you can. The audio file is around 12 minutes long”*. Participants assigned to the control condition were told *“I am now going to play you an audio file and ask you to listen to it while wearing these headphones. The audio file is around 12 minutes long”* before listening to the control intervention audio track.

In Stage 3, participants completed two more Stroop sessions (representing the post-intervention ‘time-point’), again one with tactile interference and one without. The order of tactile interference presentation mirrored that used pre-intervention. Finally, participants removed the vest and were debriefed.

Data Analysis

Reaction time data. Generalised linear mixed models (GLMMs) were used to analyse the Stroop task data, following the recommendations made by Lo and Andrews (2015). In GLMMs, the combination of fixed and random effects (as well as unknown error) predict, through a link function, a dependent variable. Fixed effects are predictor variables that are assumed to be generalizable to a wider population. Random effects are also predictor variables but are not generalizable; instead, they can be used to model individual differences. They comprise of an intercept (representing between-participant differences in the dependent

variable) and sometimes slopes (accounting for between-participant differences in the rate of change in the dependent variable).

This study employed two independent treatments (i.e., experimental and control intervention conditions) and, for hypotheses 2 and 3, modelled their effect on two dependent variables across two time-points. The random presentation of congruent and incongruent stimuli within a Stroop session and random order of tactile interference across Stroop sessions, as well as any individual differences in the effect of ATT on Stroop task performance and changes between pre and post-intervention, would be unlikely to reveal a stable covariance matrix if time-point was specified as a repeated effect. This would require an unstructured covariance matrix, which would increase the number of parameters estimated in a model and, as a result, it may fail to converge and produce reliable findings. Instead, the present study has modelled time (where appropriate) as both a fixed effect and as a random effect (defined by intercept and slope of the interaction between individuals and time-point).

The present study uses the term ‘Stroop task performance’ to refer to both accuracy (i.e., correct responses) and speed (i.e., RTs) of participants’ responses to Stroop task trials. Scarpina and Tagini (2017) recommended integrating RTs (from correct responses from within a fixed time) and errors to create a single variable. The present study used RTs of correct responses not classified as outliers (defined as correct RTs that were further than two standard deviations from a participant’s mean correct RT per stimuli pair, per Stroop session) and a global index (GI) score (calculated to represent accuracy and speed) based on a formula proposed by Gardner, Holzman, Klein, Linton, and Spence (1959).

$$GI = RT + \left(\left(\frac{RT}{SP} \right) * E_{SP} \right)$$

Where:

GI = Global Index

RT = individual RT of correct trial responses within 2SDs of a participant's mean RT of correct responses to the corresponding nine stimuli pairs per Stroop session

SP = number of stimuli pair presentation per Stroop session

E_{SP} = number of error responses per SP per Stroop session per participant

This formula aimed to generate GI scores that represented the number of errors and the speed of correct responses, reflecting attentional control. Participant correct responses for a particular stimulus set within a Stroop session were 'punished' as function of the number of error responses made within the same parameters. Parallel versions of all models were created, using GI and (separately) RT as the dependent variable.

Hypothesis 1: does tactile interference worsen reaction times in congruent and incongruent trials? The present study built two mixed effect models to test the first hypothesis. Both models (Model 1 and 2) used the same predictor variables, differing only in their dependent variable (GI or RT). The first two models used participant data from the first two Stroop sessions only to avoid any study intervention influence. The second Stroop session began immediately after the first and their data treated as a single session, without directly modelling time (i.e., a random slope was not specified). The order of tactile interference across Stroop sessions was randomised between participants (i.e., V-NV or NV-V: see Figure 1 and 2). To account for this, a binary variable was created to represent the two different orders of tactile interference presentation. This variable was nested within participants for Model 1 and 2.

Model 1 and 2 specified two fixed effect factors (both dichotomous variables): the absence/presence of Stroop interference (representing either congruent or incongruent trials) and tactile interference (representing whether the vest was NV or V during an entire 60 trial Stroop session). These models also specified two fixed effect covariates (i.e., grand-mean centred study day GAD-7 and PSWQ scores) and a fixed effect interaction term (Stroop

interference by tactile interference), as well as a single random effect (i.e., an intercept modelling between-participant variation [ID]). A significant Stroop interference predictor variable (with slower Stroop task performance during incongruent, compared to, congruent trials) would indicate a classical Stroop effect. A significant tactile interference variable (with slower Stroop task performance during Stroop sessions conducted when the vest was vibrating compared to Stroop sessions when the vest was *not* vibrating) would partially support the first hypothesis and provide evidence for a tactile Stroop effect. A significant interaction term would suggest that cross-modal stimuli have an additive impact on perceptual load. Estimated marginal means (EMMS) were calculated and simple contrasts tested to check the direction of the effects, and further support, the first hypothesis. Relevant effect sizes (Cohen's *d*) were also calculated and reported.

Hypotheses 2 and 3: does Attention Training Technique improve reaction times on both modified and standard colour-word Stroop tasks? As with hypothesis 1, two versions of the same model were built to test both hypothesis 2 (Model 3 and 4) and for hypothesis 3 (Model 5 and 6). Both of these hypotheses used data from all four Stroop sessions. For all four models, time-point was specified as a fixed effect factor and a part of a random effect, which consisted of an intercept and slope (representing between-participant differences regardless of intervention condition) with a compound symmetry covariance matrix.

The difference in the rate of change in performance between study intervention for Model 3 consisted of several fixed factors (i.e., the main effects of, and the interaction between, Stroop interference and tactile interference, as well as study intervention and its interaction with time-point). Again, study day grand-mean centred GAD-7 and PSWQ were specified as fixed effect covariates. The final two models used a new variable, labelled perceptual load (PL). How this was created depended on the findings of the first two models

built to test hypothesis 1. The fixed effect most relevant to the third hypothesis was the three-way interaction between time-point and study condition and PL. EMMs, simple contrasts, and z-scores were calculated, using the formulas described by Altman and Bland (2003), and tested. Relevant effect sizes were also calculated and reported for the final four models.

Results

Eligibility and Demographics

Two hundred and nine individuals completed the screening measures, of which 47 were identified as eligible. All were approached and 46 were able to participate in this study (female = 39; mean age = 24.8 years, range 19 to 55, $SD = 7.1$). Twenty-two self-identified as White. No participants reported having previous exposure to ATT. Participants' study day mean GAD-7 and PSWQ scores were 10.04 (range 3 to 20; $SD = 4.51$) and 65.48 (range 43 to 78; $SD = 7.06$), respectively.

Hypothesis 1: Does Tactile Interference Worsen Reaction Times in Congruent and Incongruent Trials?

Tactile interference, randomisation and correct responses. Twenty-one participants were presented with tactile interference during their first 60 Stroop task trials (Stroop session 1) and not in their second. For 25 this order was reversed. Together, participants were presented with 5,520 trials and made 267 (4.8%) error or outlier responses. This meant that data from 5,253 (95.2%) of trials were used as RTs and were converted to GI scores.

Models 1 and 2. GLMM models were built because normality testing and plots indicated that the distributions of the residuals for both GI and RT dependant variables were non-normal. Gamma distributions with log link functions were specified for Model 1 and 2. Both models used hierarchical mixed effects (i.e., participants were nested into the order in which they experienced tactile interference, they specified the same fixed effects and both

specified ID as a random intercept using a Scaled Identity covariance matrix). Table 1 shows the F-statistics for the fixed main effects, interaction term, and the covariates for Model 1 and 2. All fixed factor effect were significant predictors of both dependent variables, including the overall model (i.e., the corrected model). The only significant fixed covariate effect was PSWQ in the second model: it significantly predicted speed but not accuracy *and* speed – possibly suggesting that worried participants slowed down to avoid making errors. The random intercept for both models was significant, GI: estimate = 0.061; $SE = 0.013$, $Z = 4.61$, $p < .001$, 95% CI [0.040, 0.094]; RT: estimate = 0.062; $SE = 0.014$, $Z = 4.62$, $p < .001$, 95% CI [0.041, 0.095].

Table 2 shows the EMMs of the interaction term (Stroop interference by tactile interference) for Model 1 and 2. Tests of simple contrasts indicated that Stroop task performance was significantly impaired by tactile interference, GI: $t(5247) = -4.27$, $p < .001$, $d = -0.90$; RT: $t(5247) = -2.89$, $p = .017$, $d = -0.50$. Additionally, performance was also significantly impaired by Stroop interference, GI: $t(5247) = -21.13$, $p < .001$, $d = -4.68$; RT: $t(5247) = -20.64$, $p < .001$, $d = -4.52$. The different effect sizes indicate that Stroop interference impaired performance to a much greater extent than tactile interference. Furthermore, when controlling for Stroop interference, performance was only significantly impaired by tactile interference when it occurred during an incongruent trial, GI: $t(5247) = -6.63$, $p < .001$, $d = -1.41$; RT: $t(5247) = -3.69$, $p < .001$, $d = -0.78$. This suggests that PL can be increased by the addition of cross-modal sensory stimuli once task-demands are already heavy.

Hypotheses 2 and 3: does Attention Training Technique improve reaction times on both modified and standard colour-word Stroop tasks?

Randomisation and correct responses. Twenty-four participants were randomly allocated to the experimental condition and 22 to the control (see Figure 1). Participants'

scores for anxiety (GAD-7) on study day for the experimental condition had a mean of 9.75 (range 3 to 20; $SD = 4.79$) and for those in the control condition the mean was 10.36 (range 4 to 18; $SD = 4.27$). In terms of worry scores (PSWQ, participants in the experimental condition had a mean of 64.88 (range 43 to 78; $SD = 7.88$) and those in the control condition had a mean of 62.14 (range 57 to 77; $SD = 6.15$). No significant differences were found between study conditions in age, GAD-7, and PSWQ, age: $t(44) = 1.43, p = .16$; GAD-7: $U = 241.0, p = .69$; PSWQ: $U = 250.0, p = .76$.

Thirteen participants in the experimental condition and 12 in the control completed Stroop sessions with the vest's status order as NV-V-NV-V. For the others this was reversed (see Figure 1). Participants responded to a total of 11,040 trials (5,280 in the control condition and 5,760 in the experimental) and made a total of 519 (4.75%) error responses (including outliers). This meant that 10,521 (95.25%) data-points were used to generate the final four models.

Models 3 and 4. Again two GLMMs were built because the distributions of the residuals for both GI and RT dependant variables were non-normal, and gamma distributions with log link functions were specified. Identical fixed effect predictor variables (see Table 1) and random effects (consisting of an intercept and the slope between ID and time-point with a compound symmetry covariance matrix) were modelled. The random intercepts and slopes for both models were significant, GI (offset): estimate = 0.011; $SE = 0.002, Z = 4.58, p < .001$, 95% CI [0.007, 0.017]; GI (covariance): estimate = 0.008; $SE = 0.003, Z = 2.84, p < .001$, 95% CI [0.002, 0.013]; RT (offset): estimate = 0.010; $SE = 0.002, Z = 4.59, p < .001$, 95% CI [0.006, 0.015]; RT (covariance): estimate = 0.009; $SE = 0.003, Z = 3.15, p < .001$, 95% CI [0.004, 0.015]. This suggests that participants significantly differed in their initial Stroop task performance and their rate of change over time-points.

Table 1 shows the F-statistics for the fixed effects from both Model 3 and 4 and Table 2 the EMMs. The fixed covariate effect PSWQ was significant in Model 4 only. The interaction term time-point by intervention was significant. As expected, Stroop task performance significantly improved across time-points regardless of study intervention, GI (control): $t(10512) = 3.68, p < .001, d = 1.06$; GI (experimental) : $t(10512) = 7.17, p < .001, d = 1.98$; RT (control): $t(10512) = 3.88, p < .001, d = 1.13$; RT (experimental): $t(10512) = 7.47, p < .001, d = 1.99$. However, there were significant differences in rate of improvement in GIs' and RTs' contrast estimates between study conditions. The EMMs in Table 2, the mixed models, and two-tailed z-tests indicate Stroop task performance was significantly improved (with a large effect size) by ATT compared to the sham control intervention, GI: $z = 2.62, p = .016, d = 0.84$; RT: $z = 2.62, p = .009, d = 0.84$.

Models 5 and 6. A new ordinal variable (PL) to represent differing levels of perceptual load was created by combining Stroop interference and tactile interference dichotomous variables because Models 1 and 2 found that they both impaired Stroop task performance. Each trial was allocated a PL value, consisting of three-levels ('low', 'medium', or 'high'). If a trial had no tactile interference and used congruent stimuli, it was classified as 'low'. If it either used congruent stimuli *or* took place in the presence of tactile interference, it was classified as 'medium'. If both kinds of interference defined the trial, it was rated as 'high'.

Two GLMMs with gamma distributions and log link functions, specifying the fixed effect predictor variables shown in Table 1 and the same random effects as Model 3 and 4. The random intercepts and slopes for both models were significant, GI (offset): estimate = 0.011; $SE = 0.002, Z = 4.56, p < .001, 95\% \text{ CI } [0.007, 0.017]$; GI (covariance): estimate = 0.008; $SE = 0.003, Z = 2.89, p = .004, 95\% \text{ CI } [0.003, 0.014]$; RT (offset): estimate = 0.010; $SE = 0.002, Z = 4.58, p < .001, 95\% \text{ CI } [0.006, 0.015]$; RT (covariance): estimate = 0.010; $SE = 0.002, Z = 4.58, p < .001, 95\% \text{ CI } [0.006, 0.015]$.

= 0.003, $Z = 3.19$, $p = .001$, 95% CI [0.004, 0.015]. This leads to a similar conclusion drawn from Model 3 and 4: participants significantly differed in their initial Stroop task performance and their rate of change over time-points regardless of PL.

Figure 3 illustrates the EMMs for GIs and RTs for each PL level and each study intervention across time-points. The three-way interaction term (time-point by intervention by PL) was significant (see Table 1). Again, the fixed covariate effect was only significant in the RT model (Model 6). A visual inspection of Figure 2 indicates that Stroop task performance was worse in the experimental group than the control group pre-intervention for all PL levels, yet post-intervention, this was reversed. However, the GLMMs control for individual differences in initial performance and rate of change by modelling random effects and the intervention fixed effect was nonsignificant. Simple contrasts suggest all participants significantly improved across time-points regardless of PL (see Table 3), but the effect size of this change was consistently larger in the experimental condition. Furthermore, two-tailed z -tests using the difference in contrast estimates for the high PL data reveal that the rate of improvement for ATT participants was significantly greater than controls, with a large effect size, GI: $z = 3.28$, $p = .001$, $d = 1.11$; RT: $z = 3.26$, $p = .001$, $d = 1.01$. This suggests that a lab-based, single-exposure of ATT significantly improves attentional control under conditions of high PL more than the control intervention.

Discussion

The present study evaluates an auditory attention training exercise (ATT) using a visual attention measure (the Stroop task), modified with the addition of tactile interference. The results offer support to all three of the study hypotheses. Regarding the first hypothesis, tactile interference only contributed to PL when an individual Stroop trial consisted of incongruent colour-word stimuli (as suggested by poorer Stroop task performance). This finding aligns with the Load Theory of Selective Attention (Lavie, 2005; Lavie et al., 2004)

and indicates that Stroop task performance involves earlier and later stages of attentional control (see Guerreiro, Anguera, Mishra, Van Gerven, & Gazzaley, 2014). Regarding the second and third hypotheses, this study found evidence that ATT improved GIs and RTs more than a sham control intervention, and this improved performance is magnified under heavier PL conditions. This is the first study that indicates a lab-based, single-exposure of ATT improves attentional control using an objective measure, which does not use concern-related, or potentially emotional valence-varying, stimuli.

The study's design and statistical analyses strengthen its results. The auditory sham control intervention may not have seemed like a 'bona fide' treatment to participants (Wampold et al., 1997); however, the authors of the present paper posit that such an evaluation was as equally likely to be made by participants who had received ATT. In both groups, participants were not informed of the study objective and were blinded to whether they had been randomly allocated to receive the experimental or sham intervention. The only salient difference between interventions was that ATT included over-dubbed, spoken-word instructions. Also, the modification of the colour-word Stroop task appeared to increase the PL and SNR. The use of GLMMs allowed a degree of control over individual differences and a more fine-grained data analysis. Finally, all participants were at least mildly anxious and/or in the top quartile of worriers on the study day, making it more likely that they engaged in attentional biases (thus have poorer attentional control).

Whether there is an effect of the interaction between stimuli from different sensory modalities on PL has yet to reach a consensus in the extant literature (see Murphy, Groeger, & Greene, 2016). For example, Elliott et al. (2014) reported evidence that cross-modal interference, combining auditory and visual stimuli, in the Stroop task 'diluted' the classical Stroop effect (i.e., reduced the difference in performance between congruent and incongruent trials). However, the present study combined visual and tactile stimuli rather than visual and

auditory. Although, Turatto, Galfano, Bridgeman, and Umiltà (2004) noted that, while tactile sensory experiences occur in ‘personal space’ (i.e., spatially adjacent to the individual), the source of both auditory and visual stimuli is frequently located in ‘extra-personal space’ (i.e., at some distance from the individual). According to the ‘Garner effect’ (Garner, 1976, 1988), auditory and visual stimuli are more likely to be closer dimensionally (‘local’) and therefore more prone to interaction, and slower serial processing, than tactile and visual stimuli, which tend to be further apart dimensionally and therefore separately processed more quickly in parallel as ‘global’ stimuli. Yet other studies (including the present study) have indicated that visual and tactile interference have an additive effect on PL (e.g., Jarjoura & Karni, 2015; Kritikos & Beresford, 2002; Martino & Marks, 2000; Spence, Pavani, & Driver, 2004; Spence & Walton, 2005). These findings seem contrary to the Garner effect, though they might be explained by Pomerantz (1983) who suggested individual differences can determine whether different dimensions of stimuli are considered global (and processed more quickly in parallel) or local (and cumulatively processed serially and therefore more slowly). In terms of this study, it is possible that the high anxiety/worry participants that were recruited differ from non-anxious individuals and consider visual and tactile stimuli local.

This study used two separate metrics in parallel to measure Stroop task performance. Correct RTs could only reflect speed while GIs aimed to capture both accuracy and speed. This approach led to at least one noteworthy finding: people higher in worry seem to be more concerned about making mistakes (i.e., error responses) than quick responses. This appears to indirectly align with research that has looked at metacognitions in procrastination and worry, insofar as some positive beliefs about these processes allude to not making mistakes, yet engaging in these processes are likely to drain mental resources and impair attentional control (e.g., Cartwright-Hatton & Wells, 1997; Fernie, Bharucha, Nikcevic, Marino, & Spada, 2017; Fernie, Bharucha, Nikcevic, & Spada, 2016; Fernie, Kopar, Fisher, & Spada, 2018; Fernie,

McKenzie, Nikčević, Caselli, & Spada, 2015; Fernie & Spada, 2008; Fernie, Spada, Nikčević, Georgiou, & Moneta, 2009; Wells, 1995).

Limitations

This study is subject to several limitations. Firstly, the sample size might be considered small. However, it was larger than that suggested by the power analysis while the use of GLMMs strengthens the study's findings despite the sample size (Muth et al., 2015) and the present study's data analyses revealed mostly large to very-large effect sizes. Secondly, the study design did not assess if changes in Stroop task performance (and attentional control) were sustained in the long-term. Thirdly, ATT was delivered in a laboratory and this study's results may not generalise to more naturalistic settings. Finally, the present study only evaluated ATT and no other attention training interventions, meaning that direct comparisons could not be made.

Conclusions

This study demonstrated a lab-based, single-exposure of ATT improved attentional control and its findings support the S-REF model (and the use of ATT). Further research is required to test whether this improved attentional control reduces attentional biases. The addition tactile interference to the colour-word Stroop task increased its ability to detect changes in RTs resulting from a single-exposure of ATT. This supports the Load Theory of Selective Attention and suggests the tactile interference modifications to the colour-word Stroop task may enhance its usefulness as a tool for evaluating interventions aiming to modify attentional control in nonclinical high anxiety samples.

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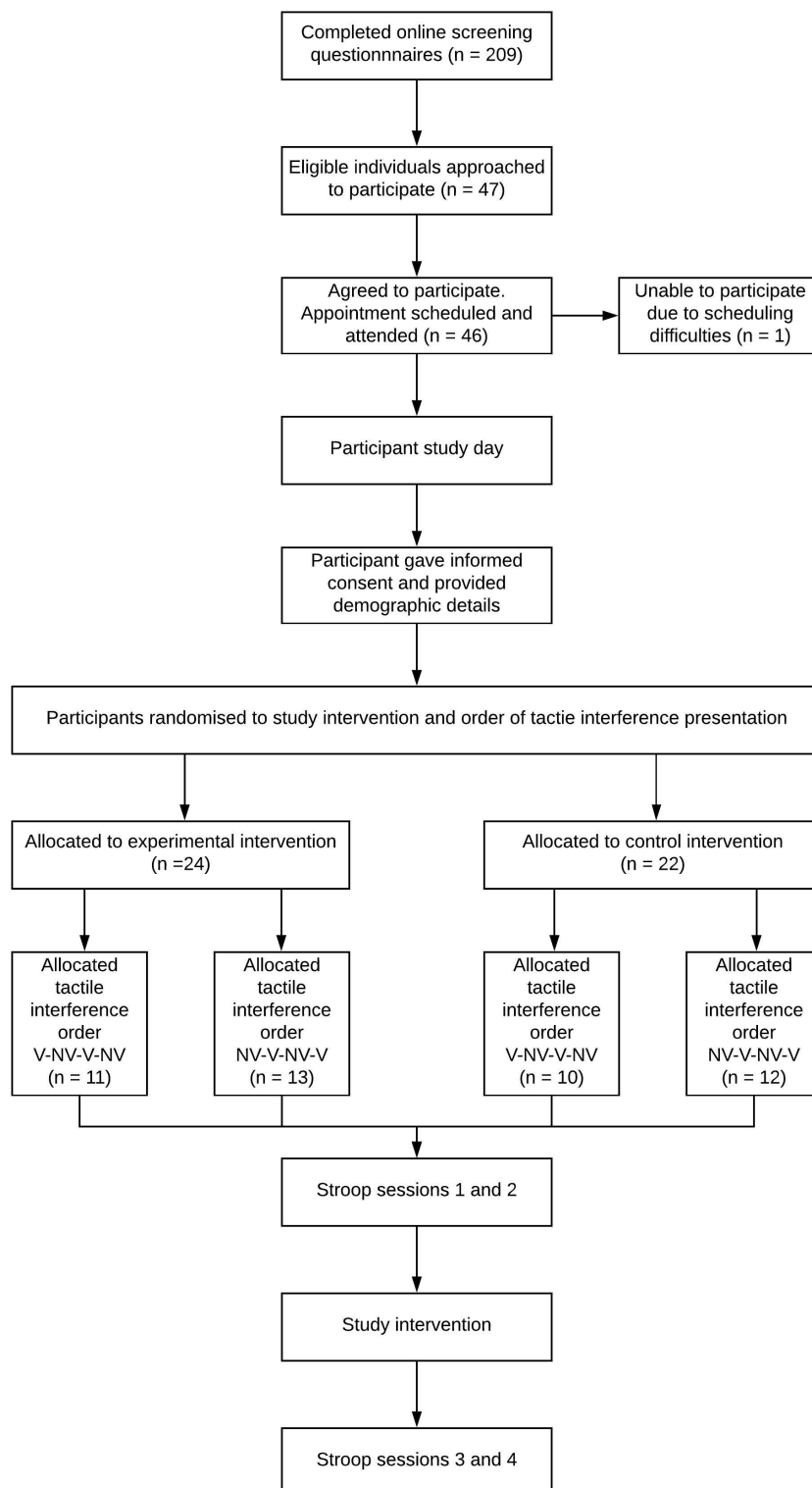
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AUTHOR ACCEPTED MANUSCRIPT

Figure 1: Participant flow



Note. NV = not vibrating; V = vibrating (tactile interference); all participants completed study day procedure within 2 hours; $n = 46$.

Figure 2: Study session procedure

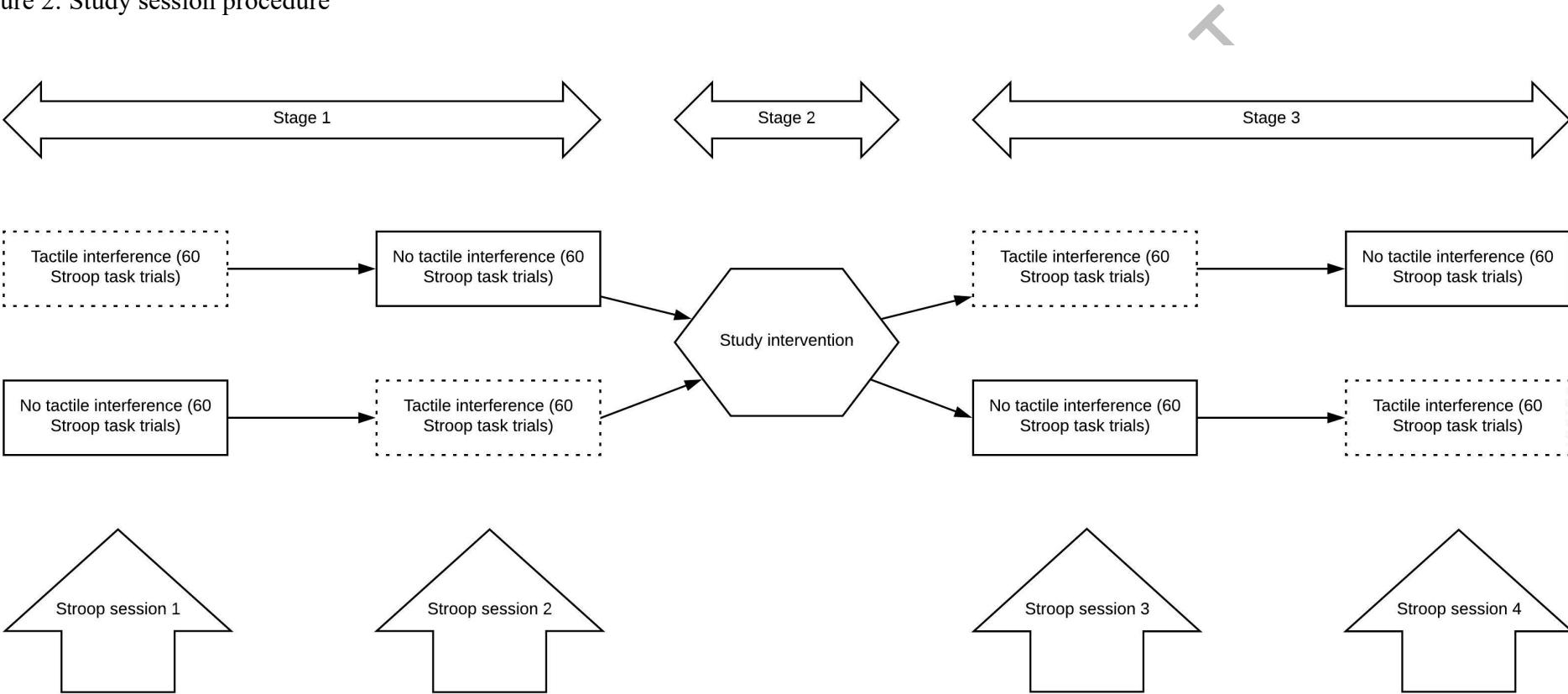
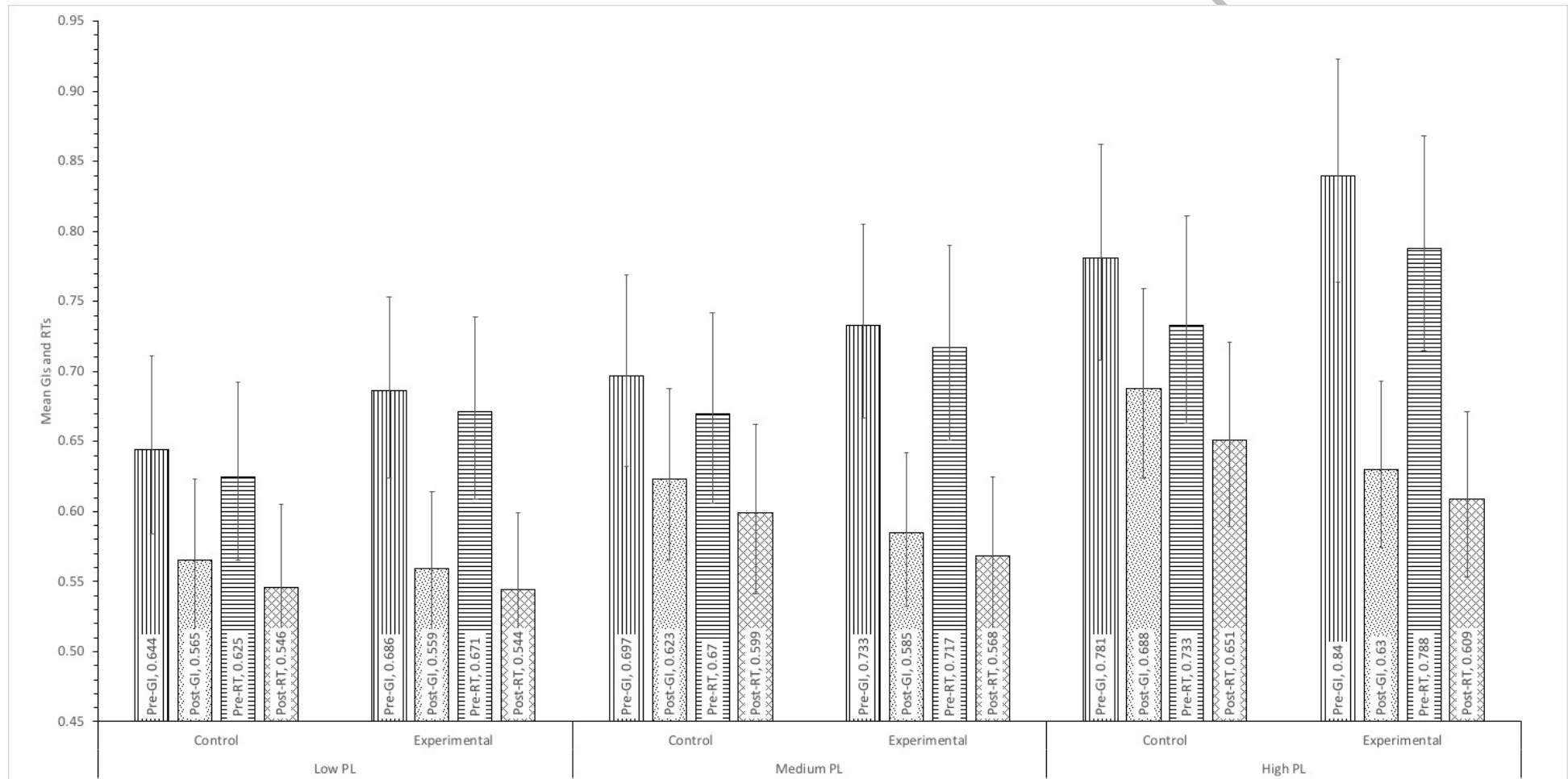


Figure 3: Clustered bar chart showing estimated marginal means of GI and RT by perceptual load for the three-way interaction term in Model 5 and 6



Note. GI = global index; RT = reaction time; PL = (low, medium, or high) perceptual load; Pre/Post = before and after study intervention (time-point); error bars represent 95% confidence intervals; number of trials = 10,521; $n = 46$.

Table 1: F-statistics for fixed effects in all models

Model	1: GI	2: RT	3: GI	4:RT	5:GI	6:RT
Fixed effect	F (<i>df_i</i> , 5374)		F (<i>df_i</i> , 10512)		F (<i>df_i</i> , 10507)	
CM	233.06 (5)***	207.54 (5)***	277.76 (8)***	264.25 (8)***	103.40 (13)***	93.59 (13)***
GAD-7	0.03 (1)	0.04 (1)	0.01 (1)	0.07 (1)	0.01 (1)	0.08 (1)
PSWQ	3.21 (1)	4.68 (1)*	3.00 (1)	4.33 (1)*	3.02 (1)	4.36 (1)*
SI	1119.75 (1)***	1021.43 (1)***	2094.75 (1)***	2006.31 (1)***	-	-
TI	18.73 (1)***	5.74 (1)*	29.39 (1)***	17.62 (1)***	-	-
SI x TI	29.84 (1)***	8.56 (1)**	29.16 (1)***	10.23 (1)***	-	-
Intervention	-	-	0.00 (1)	0.03 (1)	0.00 (1)	0.04 (1)
Time-point	-	-	63.48 (1)***	70.39 (1)***	67.53 (1)***	73.10 (1)***
Time-point x Intervention	-	-	6.58 (1)**	7.19 (1)**	6.87 (1)**	7.22 (1)**
PL	-	-	-	-	610.93 (2)***	553.62 (2)***
Intervention x PL	-	-	-	-	7.90 (2)***	7.20 (2)***
Time-point x PL	-	-	-	-	10.30 (2)***	2.06 (2)
Time-point x Intervention x PL	-	-	-	-	8.90 (2)***	6.89 (2)***

Note. GI = global index; RT = reaction time; CM = corrected model; GAD-7 = Generalised Anxiety Disorder scale 7; PSWQ = Penn State7

Worry Questionnaire; SI = Stroop interference; TI = tactile interference; PL = perceptual load; number of data-points = 5,253 (Model 1 and 2)

and 10,521 (Model 3, 4, 5, and 6); *** $p < .001$, ** $p < .01$, * $p < .05$; $n = 46$.

Table 2: Estimated marginal means for the interaction terms in Model 1, 2 (SI x TI), 3 and 4 (time-point x intervention)

Model	TI/time-point	SI/intervention group	<i>M</i> (GI: adjusted seconds; RT seconds)	<i>SE</i>	<u>95% <i>CI</i></u>	
					Lower	Upper
1: GI	No (NV)	Congruent	0.666	0.025	0.619	0.716
		Incongruent	0.771	0.028	0.717	0.828
	Yes (V)	Congruent	0.662	0.024	0.616	0.711
		Incongruent	0.811	0.030	0.754	0.872
2: RT	No (NV)	Congruent	0.649	0.024	0.604	0.698
		Incongruent	0.743	0.028	0.691	0.799
	Yes (V)	Congruent	0.648	0.024	0.602	0.696
		Incongruent	0.761	0.028	0.708	0.819
3: GI	Pre	Control	0.703	0.035	0.637	0.775
		Experimental	0.744	0.035	0.678	0.817
	Post	Control	0.623	0.031	0.565	0.687
		Experimental	0.589	0.028	0.536	0.647
4: RT	Pre	Control	0.674	0.035	0.609	0.745
		Experimental	0.721	0.035	0.655	0.794
	Post	Control	0.598	0.031	0.541	0.661
		Experimental	0.571	0.028	0.519	0.629

Note. GI = global index; RT = reaction time; TI = tactile interference; NV = not vibrating; V = vibrating; SI = Stroop interference; Pre/Post =

before and after study intervention (time-point); ; number of data-points = 5,253 (Model 1 and 2) and 10,521 (Model 3 and 4); *n* = 46.

Table 3: Simple contrasts for three-way interaction term in Model 5 and 6

Model	Intervention	PL	Contrast estimate	SE	<i>t</i>	<i>df</i>	Adjusted <i>p</i> -value.	95% CI		Within—participant <i>Cohens d</i>
								Lower	Upper	
5: GI	Control	Low	0.079	0.020	3.91	10507	< .001	0.040	0.119	0.92
		Mid	0.074	0.022	3.42	10507	.001	0.031	0.116	0.99
		High	0.093	0.025	3.76	10507	< .001	0.045	0.141	1.08
	Experimental	Low	0.127	0.020	6.19	10507	< .001	0.087	0.167	1.67
		Mid	0.148	0.021	6.91	10507	< .001	0.106	0.190	1.84
		High	0.209	0.025	8.32	10507	< .001	0.160	0.259	2.14
6: RT	Control	Low	0.079	0.019	4.24	10507	< .001	0.042	0.115	1.23
		Mid	0.072	0.020	3.66	10507	< .001	0.033	0.11	1.06
		High	0.082	0.022	3.72	10507	< .001	0.039	0.125	1.08
	Experimental	Low	0.127	0.019	6.68	10507	< .001	0.09	0.164	1.80
		Mid	0.149	0.020	7.48	10507	< .001	0.11	0.188	1.99
		High	0.179	0.022	7.99	10507	< .001	0.135	0.223	2.09

Note. GI = global index; RT = reaction time; PL = perceptual load; number of data-points = 10,521; *n* = 46.